

**Appendix I**

**Detailed Cost-Effectiveness Analysis of  
Reefer Ships**



### **Detailed Cost-Effectiveness Analysis of Reefer Ships**

This appendix contains a more thorough discussion of the cost-effectiveness analyses conducted for reefer ships than what was provided in Chapter VII. For brevity and clarity, Chapter VII addressed NO<sub>x</sub> emissions reductions for reefer ships burning 0.1 percent sulfur distillate fuel, with the necessary electrical transformer located on the shore—the most likely scenario. Appendix I further addresses the reduction of other pollutants, the use of 0.5 percent sulfur distillate fuel, and the construction of the electrical transformers on the ships.

Reefer ships visited the Ports of Hueneme, POLA/POLB, and San Diego. The cost-effectiveness analysis for cold-ironing reefers is based on the activity of reefer ships at these three ports. Because of the special needs for the cargo that is delivered (bananas, other fruit, meat), reefers generally go to the same ports and to the same terminals at these ports. During 2004, 14 reefer ships visited the Port of Hueneme, 43 other reefers ships visited POLA/POLB (two ships have since relocated to the Port of Hueneme), and another 11 ships visited the Port of San Diego. Because reefers no longer call at the Port of Long Beach, an analysis of the activity at the Port of Long Beach was not included. Tables I-1 through I-6 show the cost-effectiveness values determined for reefer ships for the three ports frequented by these ships.

Tables I-1 and I-2 provide the cost-effectiveness values for ships cold-ironing at San Diego. The tables provide similar information, but for two different electrical power loads: 1 and 2 MW, respectively. Staff received limited information for reefer ships in response to the Survey for Ocean-Going Vessels, so considered a range of electrical loads that are representative for reefer ships to complete this analysis. The 1-MW case is based on responses to the Survey, and the 2-MW case represents the midpoint of the expected range of power needed by a reefer ship. (Some of the larger reefers were analyzed at 1.2 MW and 2.5 MW, which is more representative of the reefers not carrying bananas.)

As was done previously for other ship categories, for each port, cost-effectiveness values were determined for three scenarios: 1) all ships visiting the port are cold-ironed; 2) only ships that make three or more visits per year to a port are cold-ironed; and 3) only ships that make six or more visits per year to a port are cold-ironed. In addition, the cost-effectiveness scenarios consider whether the necessary electrical transformers are constructed at the port (shore-side) or on the ships (ship-side).

**Table I-1: All Pollutants Cost Effectiveness for Cold-Ironing Reefer Ships at San Diego at 1 MW\* (Dollars/ton)**

<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$31,000	\$35,000
--shore-side transformer	\$20,000	\$23,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$28,000	\$32,000
--shore-side transformer	\$22,000	\$25,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$26,000	\$29,000
--shore-side transformer	\$22,000	\$25,000

\* Some reefer ships use 1 MW and larger reefer ships use 1.2 MW

**Table I-2: All Pollutants Cost Effectiveness for Cold-Ironing Reefer Ships at San Diego at 2 MW\* (Dollars/ton)**

<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$16,000	\$19,000
--shore-side transformer	\$11,000	\$12,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$15,000	\$17,000
--shore-side transformer	\$12,000	\$14,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$14,000	\$16,000
--shore-side transformer	\$13,000	\$14,000

\* Some reefer ships use 2 MW and larger reefer ships use 2.5 MW

In general, the average cost-effective values behave in a similar fashion to the other ship categories. Not surprisingly, the cost-effective values are more attractive for the 2-MW scenarios. The capital costs and labor costs are identical for the 1-MW and 2-MW cases; however, the greater power requirements result in more emissions—and more emissions reductions via cold-ironing. By the

same token, the electrical costs are greater for the 2-MW case, but this additional operating cost is not high enough to alter the cost-effectiveness results between the two power load scenarios.

Similar results are shown in Table I-3 through I-6 for Hueneme and POLA.

<b>Table I-3: All Pollutants Cost Effectiveness for Cold-Ironing Reefer Ships at Hueneme at 1.2 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$27,000	\$31,000
--shore-side transformer	\$16,000	\$18,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$23,000	\$27,000
--shore-side transformer	\$15,000	\$17,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$22,000	\$26,000
--shore-side transformer	\$15,000	\$17,000

<b>Table I-4: All Pollutants Cost Effectiveness for Cold-Ironing Reefer Ships at Hueneme at 2.5 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$13,000	\$15,000
--shore-side transformer	\$7,300	\$8,200
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$12,000	\$13,000
--shore-side transformer	\$7,300	\$8,300
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$11,000	\$12,000
--shore-side transformer	\$6,700	\$7,600

<b>Table I-5: All Pollutants Cost Effectiveness for Cold-Ironing Reefer Ships at POLA at 1.2 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$84,000	\$95,000
--shore-side transformer	\$43,000	\$49,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$52,000	\$58,000
--shore-side transformer	\$47,000	\$53,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$49,000	\$56,000
--shore-side transformer	\$49,000	\$56,000

<b>Table I-6: All Pollutants Cost Effectiveness for Cold-Ironing Reefer Ships at POLA at 2.5 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$41,000	\$47,000
--shore-side transformer	\$21,000	\$24,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$26,000	\$30,000
--shore-side transformer	\$24,000	\$27,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$27,000	\$30,000
--shore-side transformer	\$27,000	\$30,000

A comparison of the three ports for the “all pollutants” analyses indicates that the average cost-effective values for Hueneme are the lowest, followed by San Diego, then POLA, whose average cost-effective values are two to three times greater than those for Hueneme. Hueneme has the lowest cost-effectiveness values because it has three times the number of ships that visited often (six visits or more) than the other two ports. Conversely, POLA has the highest average

cost-effective values because most of the reefers that made only one visit to California went to POLA.

Tables I-7 through I-12 show the average cost-effectiveness values based upon NOx-only emission reductions for the three ports frequented by these ships, again for 1MW and 2-MW electrical loads.

**Table I-7: NOx Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at San Diego at 1 MW\* (Dollars/ton)**

<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$37,000	\$37,000
--shore-side transformer	\$24,000	\$24,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$34,000	\$34,000
--shore-side transformer	\$27,000	\$27,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$31,000	\$31,000
--shore-side transformer	\$27,000	\$27,000

\*Some reefer ships use 1 MW and larger reefer ships use 1.2 MW

**Table I-8: NOx Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at San Diego at 2 MW\* (Dollars/ton)**

<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$20,000	\$20,000
--shore-side transformer	\$13,000	\$13,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$18,000	\$18,000
--shore-side transformer	\$15,000	\$15,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$17,000	\$17,000
--shore-side transformer	\$15,000	\$15,000

\*Some reefer ships use 2 MW and larger reefer ships use 2.5 MW

<b>Table I-9: NOx Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at Hueneme at 1.2 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$33,000	\$33,000
--shore-side transformer	\$19,000	\$19,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$28,000	\$28,000
--shore-side transformer	\$18,000	\$18,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$27,000	\$27,000
--shore-side transformer	\$18,000	\$18,000

<b>Table I-10: NOx Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at Hueneme at 2.5 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$16,000	\$16,000
--shore-side transformer	\$8,800	\$8,800
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$14,000	\$14,000
--shore-side transformer	\$8,800	\$8,800
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$13,000	\$13,000
--shore-side transformer	\$8,100	\$8,100

<b>Table I-11: NOx Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at POLA at 1.2 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$101,000	\$101,000
--shore-side transformer	\$52,000	\$52,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$62,000	\$62,000
--shore-side transformer	\$56,000	\$56,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$59,000	\$59,000
--shore-side transformer	\$59,000	\$59,000

<b>Table I-12: NOx Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at POLA at 2.5 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$50,000	\$50,000
--shore-side transformer	\$25,000	\$25,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$32,000	\$32,000
--shore-side transformer	\$29,000	\$29,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$32,000	\$32,000
--shore-side transformer	\$32,000	\$32,000

Similar to the results for the all-pollutants case, for the NOx-only case, Hueneme has the lowest average cost-effectiveness values, and POLA has the highest average cost-effectiveness values. At the 2-MW load, both Hueneme and San Diego are more cost effective than *container* ships being cold-ironed at POLA/POLB.

Finally, Tables I-13 through I-18 show the cost-effectiveness values based upon PM-only emission reductions for the three ports frequented by these ships, again for 1-MW and 2-MW electrical loads. In all cases, the calculated cost-effectiveness values are in excess of \$300,000 per ton of PM reduced.

<b>Table I-13: PM Reductions Cost Effectiveness for Cold-Ironing Reefer Ships at San Diego at 1 MW* (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$1,400,000	\$2,200,000
--shore-side transformer	\$920,000	\$1,400,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$1,300,000	\$1,900,000
--shore-side transformer	\$1,000,000	\$1,600,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$1,200,000	\$1,800,000
--shore-side transformer	\$1,000,000	\$1,600,000

\*Some reefer ships use 1 MW and larger reefer ships use 1.2 MW

<b>Table I-14: PM Reductions Cost Effectiveness for Cold-Ironing Reefer Ships at San Diego at 2 MW* (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$740,000	\$1,100,000
--shore-side transformer	\$500,000	\$770,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$690,000	\$1,100,000
--shore-side transformer	\$560,000	\$860,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$650,000	\$1,000,000
--shore-side transformer	\$570,000	\$880,000

\*Some reefer ships use 2 MW and larger reefer ships use 2.5 MW

<b>Table I-15: PM Reductions Cost Effectiveness for Cold-Ironing Reefer Ships at Hueneme at 1.2 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$1,200,000	\$1,900,000
--shore-side transformer	\$710,000	\$1,100,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$1,000,000	\$1,600,000
--shore-side transformer	\$660,000	\$1,000,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$1,000,000	\$1,600,000
--shore-side transformer	\$660,000	\$1,000,000

<b>Table I-16: PM Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at Hueneme at 2.5 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$590,000	\$910,000
--shore-side transformer	\$330,000	\$510,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$530,000	\$820,000
--shore-side transformer	\$330,000	\$520,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$490,000	\$750,000
--shore-side transformer	\$310,000	\$470,000

<b>Table I-17: PM Reductions Cost Effectiveness for Cold-Ironing Reefer Ships at POLA at 1.2 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$3,800,000	\$5,900,000
--shore-side transformer	\$2,000,000	\$3,000,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$2,300,000	\$3,600,000
--shore-side transformer	\$2,100,000	\$3,300,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$2,300,000	\$3,500,000
--shore-side transformer	\$2,300,000	\$3,500,000

<b>Table I-18: PM Reduction Cost Effectiveness for Cold-Ironing Reefer Ships at POLA at 2.5 MW (Dollars/ton)</b>		
<b>Description</b>	<b>Distillate Fuel (0.5% Sulfur)</b>	<b>Distillate Fuel (0.1% Sulfur)</b>
<b><u>All Ships</u></b>		
--ship-side transformer	\$1,900,000	\$2,900,000
--shore-side transformer	\$950,000	\$1,500,000
<b><u>Ships making 3 or more visits</u></b>		
--ship-side transformer	\$1,200,000	\$1,900,000
--shore-side transformer	\$1,100,000	\$1,700,000
<b><u>Ships making 6 or more visits</u></b>		
--ship-side transformer	\$1,200,000	\$1,900,000
--shore-side transformer	\$1,200,000	\$1,900,000

The prior analyses have all addressed *average* cost effectiveness. As mentioned before, when cold-ironing all ships, these average values include many ships that visit a few times and a few ships that visit many times. The following analysis will address the cost effectiveness of cold-ironing an incremental ship if the shore-side infrastructure is already in place.

Table I-19 provides incremental cost-effectiveness values for NO<sub>x</sub> reductions only, PM reductions only, and “all pollutants.” These values are based on distillate fuel, the transformer located on shore, and a 2.5-MW electrical load. The average electrical rate assumes that there is already sufficient cold-ironing activity at the berth to minimize the effect of demand charges.

Not surprisingly, the incremental cost-effectiveness values improve significantly with more visits made by a ship. In general, by the third visit, the incremental cost-effectiveness value is less than half of that for one visit. Note that the cost-effectiveness values for Hueneme and POLA are lower than those for San Diego. This is due to the smaller ships visiting San Diego and the higher electricity rates for the San Diego area.

<b>Table I-19: Incremental Cost Effectiveness to Retrofit a Reefer Ship Using Distillate Fuel (0.1 percent sulfur) and 2.5 MW (Dollars/Ton)</b>			
<b>Visits/Port</b>	<b>NO<sub>x</sub></b>	<b>PM</b>	<b>All Pollutants</b>
<b>San Diego</b>			
1	\$41,000	\$2,400,000	\$38,000
2	\$23,000	\$1,300,000	\$21,000
3	\$17,000	\$970,000	\$16,000
<b>Hueneme</b>			
1	\$32,000	\$1,900,000	\$30,000
2	\$17,000	\$990,000	\$116,000
3	\$12,000	\$700,000	\$8,500
<b>POLA</b>			
1	\$32,000	\$1,200,000	\$26,000
2	\$16,000	\$610,000	\$14,000
3	\$11,000	\$660,000	\$11,000